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THE YEAR 1816—THE CAUSES OF ABNORMALITIES [1]

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SYNOPSIS

The year 1816 is famous from the meteorological point of view. More has been written about this year than any other. All the older books on climate and weather and many biographies and histories have something to say about it. There are many references to it in the periodical literature but the statements are often inaccurate and exaggerated.

Good observations were made in Williamstown, Mass., from 1816 to 1838. The observations for 1816 as compared with those from 1816 to 1838 and from 1901 to 1923 are discussed. The year 1816 was the seventh coldest, averaging 44.3° F. or 1.3° F. below normal. The two coldest years (1816–1838) were 1836 and 1837, each averaging 42.6° F., or just 3° F. below normal. Thus 1816 as a whole was not record-breakingly cold. February, October, November, and December of 1816 were too warm, while the remaining months were much too cold. The year was thus exceptional because of a very cold summer. The lowest temperatures at 7 a. m. for June, July, and August, 1816, were 35° F., 43° F., and 37.5° F., respectively, and these were the lowest for these months for the 23-year period. The individual cold spells during the summer months are discussed next and the observations taken at other stations during 1816 are compared with those at Williamstown

In the second part the possible reasons why 1816 was so abnormal are treated. There had been the violent volcanic eruption of Tomboro in April, 1815. A weak sun-spot maximum had also occurred during 1816.

In the third part the possible causes of the abnormality of any month or year are discussed. Volcanic eruptions, changes in the activity or condition of the sun (sun spots, solar constant), changes in the surface temperatures of the oceans, changes in the composition of the atmosphere (ozone, carbon dioxide), and accidental causes are treated in order.

PART I

The year 1816 is famous from the meteorological point of view. More has probably been written and said about this year than any other. It is famous as *the* cold year and is often called "the year without a summer," "poverty year," or "eighteen hundred and froze to death."

All the older books on meteorology, climate, or weather have much to say about it. Take as an example Blodget's Climatology of the United States published in Philadelphia in 1857. Data concerning the year are found in many tables and there are many references to it. On pages 147 and 148 there are these comments: "But during this period the most remarkable depressions of temperature in the summer months known to all history of thermometer measurements occurred in the period from 1811 to 1817. Of these 1812 and 1816 were the coldest. In the Northern States snows and frosts occurred in every month of both summers; Indian corn did not ripen, fruits and grains of every sort were greatly reduced in quantity, or wholly cut off. * * * In England 1816 was almost as extreme as in the United States."

Most of the biographies and histories (particularly State and local histories) covering this period also have something to say about this year 1816. Take for example Chauncy Jerome's History of the American Clock Business for the past Sixty Years and Life of Chauncy Jerome. This was written in 1860 when Jerome was 67 years old. He was thus 23 years old in 1816. On pages 31 and 32 he has something to say about the famous year. He was then living in Plymouth, Conn.

> The next summer was the cold one of 1816, which none of the old people will ever forget, and which many of the young have heard a great deal about. There was ice and snow in every month in the year. I well remember the 7th of June, while on my way to work, about a mile from home, dressed throughout with thick woolen clothes and an overcoat on, my hands got so cold that I was obliged to lay down my tools and put on a pair of mittens which I had in my pocket. It snowed about an hour that day. On the 10th of June, my wife brought in some clothes that had been spread on the ground the night before, which were frozen stiff as in winter. On the 4th of July I saw several men pitching quoits in the middle of the day with thick overcoats on, and the sun shining bright at the time. * * * Not half enough corn ripened that year to furnish seed for the next.

Jerome is usually quite accurate in his statements and free from exaggeration so this can probably be taken at almost face value although written from memory 44 years after the event.

Thompson in his History of Vermont says: "It is universally conceded that the year 1816 was the coldest ever known in Vermont."

There are also many casual references to this year in the periodical literature all the way from 1816 to date. In fact references seem to be more frequent during the last few years. If any month is at all cold, the year 1816 is at once recalled as the awful example. The Literary Digest for September 6, 1924, contains this:

> In 1816 there were no crops raised north of the Ohio and Potomac and but scanty returns much farther south. Frost, snow, and ice appeared in every month of spring, summer, and fall.

That is plainly somewhat exaggerated.

If all the statements in climatologies, in books on the weather, in biographies, in histories, and in the periodical literature were collected, they would form a sizable volume. They would not, however, be particularly valuable unless subjected to a very close scrutiny as there are many inaccurate and exaggerated statements. The statements quoted are good examples of what is found.

Fortunately meteorological observations were commenced in Williamstown, Mass., on January 1, 1816. The temperature was noted three times a day at 7 a. m., 2 p. m., and 9 p. m. The amount of precipitation, the wind direction, and the character of the day were also noted, and there were many comments. There were no maximum and minimum thermometers so the highest and lowest temperatures were not recorded and the barometric pressure was also not observed that year. It is interesting to note that the moon's age was very carefully recorded. That was discontinued, however, after eight or nine years. Meteorological observations have been

[1] Annual presidential address read before the American Meteorological Society at Washington, D. C., Dec. 31, 1924.

continued in Williamstown to date, so that the record is now 109 years long. For the first 23 years, that is, from 1816 to 1838, inclusive, the observations were made with great care, they are apparently uniform, there are no breaks, and they have been carefully averaged. These observations will thus serve to show how abnormal the year 1816 was as compared with the 23 years from 1816 to 1838. Williamstown is also well located for a critical study of the year 1816. It is not near the sea. Taking New York and New England together, it is approximately centrally located.

The observations in 1816 were taken within a few hundred feet of the Hopkins Observatory of Williams College which was built in 1838. It is not known just what kind of a shelter or what instruments were used. The observations for 1816 to 1838 were bound up in book form, probably before 1850, and that has kept them intact until the present time.

Table 1 contains the average monthly and the average yearly temperatures for the 23 years, 1816 to 1838, inclusive. The normals for the months and the year, determined by averaging the 23 corresponding values are also given. The exponent 3 indicates the lowest average and the exponent 2 the next lowest. The exponent 3 indicates the highest mean. It will be seen that the normal yearly temperature for the 23 years comes to 45.6° F. The two coldest years were 1836 and 1837, each with an average of 42.6° F., and thus just 3° F. below normal. The year 1816 averaged 44.3° F. or 1.3° below normal, and was only the seventh coldest. Thus the year 1816 was not phenomenal because the year as a whole averaged so low. The years 1836 and 1837, which are but seldom mentioned, were much worse. When the individual months are considered, it will be noted that February, October, November, and December were too warm while the remaining months were too cold. May was the second coldest for the 23 years and averaged 3.8° F. below normal; June was the second coldest for 23 years and averaged 5.2° F. below normal; July was the coldest for 23 years and averaged 5.4° F. below normal; August averaged 2.1° F. below normal and September averaged 3.9° F. below normal. The reason why 1816 is considered to be so abnormal begins to be apparent. It is because the three summer months June, July, and August, and the two adjacent months, May and September, were all far below normal. And yet these departures from normal are not extremely large and only one was the largest for 23 years. If the cold months had not been consecutive, or if the cold spell had come during the winter, spring, or autumn instead of midsummer, the year 1816 would never have been famous. It is also to be noted that the summer of 1837 with the same five months, 4.7°, 2.6°, 3.5°, 2.1°, and 2.4° below normal, was almost as bad, and yet 1837 is seldom heard of.

The reason why 1816 was considered so abnormal becomes still more apparent when the lowest observed temperatures during each of the summer months for the 23 years are tabulated. These are indicated in Table 2. It must be remembered that these are not minimum temperatures but temperatures observed at 7 a. m. or 9 p. m. It will be noted that the lowest temperatures for all three months came in 1816. During June a temperature of 35° was noted; during July 43°, and during August 37.5°. These were all 7 a. m. temperatures. One naturally wonders how low the minimum temperatures were. There are two ways of getting at this. In the first place, in some places in the observation book the sunrise temperature was given along with the 7 a. m. temperature if it was particularly low. All these cases have been indicated. The average difference is between 3 and 4 degrees. Secondly, Table 3 gives for Albany, N. Y., the average difference for the three summer months, June, July, and August, between the minimum and the 7 a. m. temperatures for the last 10 years, 1915 to 1924, inclusive. It will again be seen that the minimum temperatures should have been around 4 degrees lower than the 7 a. m. temperatures. That means that it froze every month during the summer of 1816, since the minimum temperatures were probably about 31°, 39°, and 33°, and 39° is the frost limit for Williamstown.

The marginal comments in the observation book in connection with these three low temperatures and a description of the famous cold spells are next in order. The famous cold spell during June and, in fact, the most remarkable during the summer, came from the 5th to the 11th. On June 5 at noon the temperature was 83° F. Thunder showers came quickly and the wind shifted into the northwest with vigor. In fact, it was cloudy and squally and the temperature was forced steadily down. On the 6th at 7 a. m. the temperature was 45¼° F., and that was *warmest* for the day. The marginal comment says: "Snowed several times—in Peru the ground was white—also in Cheshire, Windsor, and west of us on mountains." Jerome's comment on this same day at Plymouth, Conn., will also be recalled. He said: "It snowed about an hour that day." Zadock Thompson, in his History of Vermont, published in 1842, says: On the 8th of June snow fell in all parts of the State, and upon the highlands and mountains to a depth of 5 or 6 inches." There seem to have been snow squalls over a large part of New England. The date is not quite the same, but that is probably a lapse of memory. At 7 a. m. on the 7th the temperature was down to 35° F. As the wind was still blowing and there were some clouds, it is a question if the minimum temperature had been much lower. The wind continued steadily in the northwest and the 7 a. m. temperature on the 8th was 40.5° F., on the 9th, 40.5° F., on the 10th, 40⅝° F., and on the 11th, 38° F. The culmination evidently came in the early hours of the 11th. The marginal comment says: "Heavy frost—vegetables killed—at 5 o'clock, temperature 30.5°." By 7 a. m. the wind was south, the temperature 38°, and rapidly rising.

All this can only be interpreted in terms of an extensive area of high pressure which was ushered in by strong northwest winds and snow squalls, and dominated the weather for six full days. This was the only cold spell during June, the rest of the temperatures being quite moderate. In fact, on the 24th the temperature was up to 94° F., which is very high for Williamstown. In July the same thing took place on a more moderate scale. On the 6th the wind shifted to the northwest with vigor and the temperature was forced steadily downward. This time it lasted four days, and the lowest temperature was 43° F. at 7 a. m. on the 9th. The single marginal comment is "frost." There was no snow this time. The rest of July was again very seasonable. During August there was no pronounced cold spell. The lowest temperature was 37.5° F. at 7 a. m. on the 29th. The marginal comment is "Severe frost—some vegetables (green corn) killed—few solar spots." It is interesting to note that solar spots and a change in the phase of the moon were being carefully observed. It was apparently considered at the time that these two things were the chief causes of abnormal weather. Thus the chief abnormality of the summer consisted of these three cold spells. It snowed during the cold spell in June only. It barely froze in July.

The average temperature for the different months and the years were computed, using the 7 a. m., 2 p. m., and 9 p. m. temperatures. In fact, they were computed from daily temperatures which were found by the formula ⅓ (7 a. m. + 2 p. m. + 9 p. m.). The formula ¼ (7 a. m. + 2 p. m. + 9 p. m. + 9 p. m.) is considered much better and was used for a time by the United States Weather Bureau. Now, of course, ½ (max. + min.) is always used to compute an average daily temperature. These differ, however, but little from each other. Table 4 gives the average monthly temperatures for 1816 when the daily temperatures were computed by both formulæ. It will be seen that the average difference is 0.65° F. The summer difference is a little less than a degree, and the winter difference about four-tenths of a degree. The difference between average monthly temperatures when the daily temperatures are computed by ¼ (7 a. m. + 2 p. m. + 9 p. m. + 9 p. m.) and from ½ (max. + min.) has often been investigated, and the difference is only a few tenths of a degree. Thus the values given in the table for the various months and for the years 1816 to 1838 are only a few tenths of a degree higher than if the daily temperatures had been computed from ½ (max. + min.).

Corresponding data for the last 23 years (1901 to 1923, inclusive) will be of interest. In Table 5 are given the average yearly temperatures for the 23 years 1901 to 1923, inclusive. The normals are also given. The normal yearly temperature for 1901 to 1923 comes out 45.52° F., while the normal yearly temperature for 1816 to 1838 comes out 45.57° F. And this in spite of the fact that the first is computed from ½ (max. + min.) while the last rests upon ⅓ (7 a. m. + 2 p. m. + 9 p. m.). The departures of the coldest May, June, July, August, and September from normal are 8.3°, 4.2°, 2.8°, 5.4°, and 3.7°. The departures of the same five months of 1816 from normal were 3.8°, 5.2°, 5.4° 2.1°, and 3.9°. These are of the same order of magnitude. Thus summer months have departed from normal just as much or more during the last 23 years as in the months of 1816, only the big departures did not all come in the same year.

Table 6 contains the lowest minimum temperature for June, July, and August for the years 1901 to 1923, inclusive. The very lowest values are 35° F. for June 1912, 41° F. for July 1912, and 35° F. for August 1904. These are minimum temperatures. Compare them with 7 a. m. temperatures of 35° F. for June 1816, 43° F. for July, and 37.5° for August. The 1816 minimum temperatures were thus probably lower by a very few degrees only than the lowest observed from 1901 to 1923, inclusive.

The agreement of Williamstown observations with those taken at other stations during 1816 is a matter of importance. Temperature observations were begun in North America perhaps as early as 1730 or 1740. Very often they were continued at a station only a year or two. It is hard to say at just how many stations observations were being made during 1816—at certainly less than 10 stations. Blodget, in his climatology, gives the departure from normal of the various months of 1816 for four places, namely, Salem, Cambridge, New Bedford, and Williamstown. These, with the New Haven values which are not included, are given in Table 7. Williamstown was included but these values have been put in parenthesis since the normals were based on only a few years, 1816–1819. The values derived from the normals based on the years 1816–1838 are given instead. When these are used it will be seen that the agreement among all five stations is good.[3] The departure from normal was practically the same over all the northeastern part of the United States. The lowest temperatures observed at New Bedford during June, July, and August, 1816, were 38°, 50°, and 48°, respectively. These are apparently minimum temperatures. It is interesting to compare them with the three lowest 7 a. m. temperatures at Williamstown which were 35°, 43°, and 37.5°, respectively. The normal annual temperature (1816–1838) at New Bedford is 48.6°, while at Williamstown the (1816–1838) value is 45.6°, just 3° F. lower. Williamstown was thus harder hit by the cold than New Bedford, which one would expect from the latter's location near the sea.

Thus as summary it may be stated that 1816 was a phenomenal year *not* because the year as a whole averaged so low, *not* because each month of the year was uniformly cold, but because the three summer months and the two adjacent ones were all cold, and chiefly because the lowest temperatures were extremely low in a locality where the difference of a very few degrees in the lowest temperature during the summer months makes all the difference between a severe frost and the absence of frost.

PART II

Why was 1816 so abnormal? It is easy to ask questions but not so easy to answer them. The year 1816 belongs to that famous group of six years, 1812 to 1817, inclusive, all of which were cold over the whole world. According to Prof. William J. Humphreys as given in his masterly book, Physics of the Air, the world as a whole during 1816 was 0.90° C. or 1.62° F. below normal. When we say the whole world was cold, of course we mean the average departure from normal of the stations considered was 1.62° F. The vast oceans were without stations and there were also great land areas without stations as well, nevertheless, the stations considered were as typical of the whole earth as possible. According to Humphreys, these cold years were caused largely, if not entirely, by volcanic eruptions which put dust into the upper atmosphere. This idea is fully elaborated in the book just mentioned. In a crude form the idea may have originated with Benjamin Franklin, or even earlier, as Humphreys himself says. This volcanic dust in the upper atmosphere is much more efficient in shielding the earth from the sun's ether waves than in retaining the radiation from the earth and thus acts to keep the earth cool. There was an eruption of Soufrière, St. Vincent, April 30, 1812, and of Mayon, Luzon, in 1814. The chief volcanic eruption, however, was that of Tambora, Sumbawa, April 7 to 12, 1815.

This was a really great eruption and ranks with the four or five largest during the last two centuries. It is estimated that from 37 to 100 cubic miles of dust, ashes, and cinders were thrown into the atmosphere. Some 60,000 people lost their lives. For three days there was darkness at a distance of 300 miles and the explosions were heard at a distance of nearly a thousand miles. In Williamstown it will be remembered that the year 1816 was 1.3° F. below normal, and Table 8 contains the departure from normal of the various months for both 1816 and 1817. During the period 1816 to 1838 there was another group of particularly cold years the world over. These were 1835, 1836, 1837, and 1838. In Williamstown the years 1836 and 1837 averaged the coldest (3° F. below normal) of any years during the period. The de-

[3] Observations of some value were probably made during 1816 at Castine, Me.; Sharon, Conn.; Deerfield, Mass.; and Philadelphia.

partures of the various months of these years from normal are also given in Table 8. The great eruption of Cosequina, Nicaragua, had occurred on January 20, 1835. During the last 23 years (1901 to 1923) The greatest volcanic eruption was that of Katmai, Alaska, June 6, 1912, which caused the earth as a whole to average 0.54° below normal. The average monthly temperature in Williamstown hardly shows this, however. The departures from normal for this year and 1913 are given in Table 8. The cold months in 1912 came before the eruption. It is very remarkable, however, that the lowest minimum temperatures, as indicated in Table 6, all come during 1912 and 1913. It is dangerous to generalize from a few observations, but two conclusions seem fairly well established. In the first place, during the two or three years which follow a volcanic eruption which may cause the temperature of the earth as a whole to be, say, 1° F. below normal, it is impossible to say just which months, if any, are going to be below normal at a particular station. And secondly the chief effect of a volcanic eruption seems to be to cause the minimum temperature, especially of the summer months, to be particularly low.

But to return to the original question, is there any other known reason why 1816 should have been so abnormally cold? A sun-spot maximum occurred during 1816. To be sure it was a poorly marked maximum since the Wolfer sun-spot number was about 45 for the year. It will be remembered that these numbers vary from practically 0 during a minimum to perhaps 150 during a sharply-marked prominent maximum. The earth as a whole is supposed to be perhaps 0.5° F. colder than normal during a sun-spot maximum.

PART III

We can now leave the year 1816 and raise the general question. If any particular year or month is abnormal, what are the possible reasons for the abnormality? When this question has been satisfactorily answered, a long step has been taken toward being able to predict the characteristics of a month a considerable time in advance. This is a very practical problem and the pressure for its solution is great.

A *first* possible cause is one that has already been considered in connection with the year 1816, namely, dust thrown into the upper atmosphere by violent volcanic eruptions. The four or five more violent eruptions which have occurred during the last century and a half seem to have lowered the temperature of the whole earth about 1° F. on the average. It must be emphasized also that at any particular station it is impossible to state just what months during the two or three years following a violent eruption are going to be below normal, and how much. This means that there are other causes of abnormality which are far more powerful than volcanic dust.

A *second* cause is the changes in the activity or condition of our sun. The solar constant and the sun spots are the two indices of solar activity which are being critically and constantly observed at present and about which we know most. There is a growing tendency at present to ascribe all abnormalities in our weather to changes in the sun.

We have, in truth, a wonderful central sun for our solar system—a vast body 864,000 miles in diameter and at a temperature of nearly 11,000° F. On its surface, or better probably, in its outer layers, there are the sun spots and the white spots or faculæ. The outermost layer is the corona which may extend at times even two or three million miles from the sun. All of these things have been carefully observed, some of them for more than a century. The sun spots are probably the most remarkable. They are distinctly periodic with a period of 11.2 years, as regards number, size, and place of occurrence. This is only an average period, however, as the time interval from maximum to minimum varies from 8 to 17 years. The rise from minimum to maximum is rapid, requiring about 4.6 years, while the fall is slower requiring 6.5 years. The spottedness of the sun is expressed by means of the Wolfer sun-spot numbers which depend upon and are computed from both the number of spots and the number of groups.[3] These numbers are practically zero for a sun-spot minimum and rise to almost 150 for a very prominent maximum. The sun spots are also strongly magnetic, two near-by spots usually having opposite polarity. This periodicity in the activity of the sun is also to be noted in the faculæ, the shape and extent of the corona, and in the energy sent out to the earth by the sun. The corona has well-marked polar tufts and long equatorial streamers at the time of sun-spot minimum. As the spots increase the form becomes more quadrangular and the polar tufts are less marked. At the time of sun-spot maximum the surrounding corona is larger and practically uniform. The energy sent out by the sun and received by the earth also varies with this same period. It is called the solar constant and its average value is 1.946 calories per square centimeter per minute at the outside of the earth's atmosphere. Its periodicity is, however, not well marked, the value at sun-spot maximum being only about 0.03 calories higher than average,[4] or, as Abbot expresses it, a change of 100 in the Wolfer number means a change of 0.07 calories. Thus as a summary it may be said that everything connected with the sun is subject to irregular fluctuation and to a periodic variation with a period between 11 and 12 years.

How can this marvelous sun, through any change in its activity or condition, affect the weather of this earth roughly 93,000,000 miles away with nothing between but empty space, that is, luminiferous ether? First, it can affect the earth through the quantity and quality of the ether waves sent; secondly, by its magnetic field of force; thirdly, by means of its electrostatic field of force; fourthly, by means of charged electrons or penetrating radiation which, originating in radioactive material or atomic disintegration, may make their way to this earth.

The quantity of ether waves sent out by the sun, that is, the sun's insolation, is measured by the solar constant. The average value, as stated above, is 1.946 calories. It is subject to a small periodic variation with the sun-spot period and to much larger irregular fluctuations. How does a change in the solar constant affect our weather? That has been discussed by many investigators, chief among them being Arctowski, Helland-

[3] The periodicity of sun spots was first proved by Schwabe in 1843. The sun-spot numbers were first proposed and prepared by Wolf and later revised and continued by Wolfer. They are computed from the formula $N=(10g+f)$, where g is the number of groups and f the number of spots. The sun-spot numbers are known from about 1749. The values from 1749 to 1901 were published in the MONTHLY WEATHER REVIEW for April, 1902, and from 1902 to 1919 in MONTHLY WEATHER REVIEW for August, 1920, and for 1920, 1921, 1922 in the MONTHLY WEATHER REVIEW for January, 1923. They are now published about every three months in the Journal of Terrestrial Magnetism and Atmospheric Electricity. They are, of course, published and discussed in many other places as well.

[4] Measurements of the solar constant were made as far back as 1837 by Pouillet. Then follows the work of Violle, Crova, Chowlson, Angström and others. In recent times the chief investigators have been Langley, Kimball, and, finally, Abbot and Fowle. The results of their magnificent work are published in the Annals of the Astrophysical Observatory of the Smithsonian Institution. Four large volumes have appeared. Values of the solar constant as determined by Abbot and Fowle exist for certain months in the year from 1905 on. Since June, 1918, continuous determinations have been made. Volume 4 contains the values as far as July, 1920.

Hansen and Nansen, Clayton, Humphreys, and Abbot.[5] It is necessary, in answering the question, to study the weather of the whole world. The correlations are but poorly marked. It would seem that a rise in the value of the solar constant causes a rise of temperature in an equatorial belt and also in a near-polar belt (below 60° north latitude) while in between there is a fall in temperature. This increases the interzonal temperature differences and this very likely results in an increase in storminess, particularly along the margins of these belts. If the solar constant should increase 0.05 calories and stay at the new value it is hardly possible at present to say for any given station just what the difference in weather would be. And that is the simplest case.

As to the quality of ether waves sent us by the sun, it is doubtful if there is any change. The smaller corona at the time of sun-spot minimum might allow more short ether waves to pass. This would favor the building of ozone in the upper atmosphere and a large quantity of ozone would operate to keep the earth warm. It is possible perhaps in this way to explain the slightly higher temperature of the earth during a sun-spot minimum. All this is very far from a proved case, and the experts do not agree.

The sun has a strong and varying magnetic field of force. At the high temperatures existing in the sun it is very doubtful if there can be any permanent magnetism connected with it. It is essentially gaseous and the temperature is too high. The mangetic field of force is more likely caused by the circulation of charged particles, particularly in sun spots. The sun's magnetic field of force, the sun's electrostatic field of force, and the charged electrons and penetrating radiation coming from the sun without doubt affect greatly the earth's magnetism, the earth's atmospheric electricity, and the earth currents. Here the correlations are excellent. It is a grave question if they affect the earth's weather. There are those, Huntington in particular, and others, who have argued for the possibility of a magnetic or electrical control of our weather changes. It seems at present very far from a proved case. One can see of course possible connections. There are charged particles in our own atmosphere. These are in motion in connection with a cyclonic storm and thus such a storm must be weakly magnetic. It would thus be controlled to some extent by the earth's magnetic field of force. There are those who claim that the LOWS follow courses which seem to be more related to the magnetic than to the geographic pole. I would not for a moment belittle those who have made long and laborious investigations along these lines. Their work is necessary and very valuable.

There still remain to be mentioned many investigations showing the relation between our weather and the sun-spot period. This same period exists in our temperatures. The earth as a whole is about 0.5° F. warmer at sun-spot minima than normal. The same period is to be found in the number of storms. For certain belts they are more numerous, in other belts less numerous, at the time of sun-spot maximum. The same period may be found in our barometric pressure, and perhaps rainfall. In all cases the difference is very slight. Among the workers along this line I might mention Arctowski, Köppen, Walker, Helland-Hansen and Nansen, Abbot and Fowle, Humphreys, and Huntington. It is usually stated that these investigations show the relation of our weather to sun spots. This is hardly correct. It is hard to see just what connection sun spots as such have with our weather. If we admit magnetic or electrical control, the sun spots might directly affect the weather. They are rather to be considered simply as an index of solar activity and our weather changes and abnormalities are due to changes in this activity. It should also be mentioned in passing that if a magnetic or electrical control of the weather is ever once admitted, then we are wandering in the maze of lunar and planetary control, for these bodies are all magnets and charged bodies. And there are, of course, those who believe in just this planetary influence. We hear of the eight-year Venus period in connection with our weather, etc., and even the ghost of Vulcan is occasionally called up.

A third cause of abnormalities may be found in unusually high or low temperatures of the surface water of an ocean over a large area. This has been but recently brought to the fore and emphasized as a possible cause of abnormal weather. Science Service News as given in Science for June 6, 1924, contains this. I am quoting only in part:

> Unusually warm water in the northwestern Atlantic Ocean, and especially over the Grand Banks of Newfoundland, is considered by the United States Weather Bureau experts as a very likely cause for one of the wettest month of May in years.

Sir Frederic Stupart gave a paper at the British Association meeting at Toronto in August, 1924, on "The variableness of Canadian winters." An abstract of the paper is contained in the Bulletin of American Meteorological Society for August–September, 1924. I am quoting from this abstract:

> In normal seasons North Pacific cyclonic areas usually move southeastward, with their centers well off the coast until at about the latitude of northern British Columbia they enter the continent while anticyclonic conditions of moderate intensity and low temperature prevail in Yukon and the Mackenzie River.
>
> In certain years, however, the Pacific cyclonic areas are less intense and enter the continent farther south, while the great anticyclonic developments occur in the far north and sweep southeastward over Canada, accompanied by severe cold waves, which not infrequently reach the Atlantic coast. These conditions lead to abnormally cold winters in Canada.
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> In other years the North Pacific cyclonic areas appear to be of such intensity that they force their way into the continent in high latitudes and actually prevent the formation of anticyclones and their concomitant low temperature. These conditions lead to mild winters in Canada.
>
> The Meteorological Service is investigating as to whether there is any connection between the temperature and position of the Japan current and the behaviour of these cyclonic areas.

It may thus be true that a change from normal of the surface temperature of an ocean over a large area may influence the semipermanent highs and lows (the centers of action, as they are sometimes called) and thus affect the track followed and the characteristics of the moving HIGHS and LOWS so that at any given station a month may be abnormal as regards temperature, precipitation, number of storms, etc.

But why does the surface temperature of the oceans over a large area depart from normal? It may in part be due to heating or cooling on that spot, but more likely it is due to some change in the direction, velocity, quantity of water carried, or temperatures of ocean currents. There are many factors which determine these matters in connection with ocean currents. Chief among them may be mentioned temperature differences between Equator and Pole, rotation of the earth, configuration of the shore line, differences in salinity, inflow of water, direction and velocity of the wind. Some of these factors are constant; others change. The heating of the equatorial waters depends upon the insolation from the sun, In other words,

[5] In the two recent excellent research books, Earth and Sun, by Ellsworth Huntington, and World Weather, by H. H. Clayton, these matters are fully discussed. There are numerous references to the periodical literature. These books are good places to begin if anyone wishes to read up on these subjects.

this would vary with the solar constant. Perhaps we are getting back again to the changes in the solar constant as the *primary* cause of abnormalities in the weather. Changes in the solar constant would thus cause a different amount of heating of the equatorial waters. This would affect the ocean currents, which would in turn determine the temperature of the surface water over a large area. A change here would affect the semipermanent HIGHS and LOWS which would modify the paths followed and the characteristics of the moving HIGHS and LOWS, which would cause the weather at a given station to be abnormal. The chain of events is a long one and a considerable time interval must elapse between primary cause and result. Thus a change in the solar constant might cause a weather abnormality at a given station months or even years later. The two places where changes in the surface temperatures of the ocean are going to cause the greatest abnormalities in North American weather are probably between Iceland and the Grand Banks and south of the Aleutian Islands.

A *fourth* cause of abnormalities may be found in changes in the composition of the atmosphere, particularly in its carbon dioxide (CO_2) and ozone content. The ocean is a great storehouse for carbon dioxide, and any change in its temperature would thus put into the atmosphere or take from it large quantities of CO_2. It has been pointed out, however, that the quantity of CO_2 in the atmosphere is so large (a layer about 10 feet thick) that a change of even 20 per cent in the amount would not change the selective absorption which is due to it. Ozone in the upper atmosphere has already been mentioned. A change in the quality of the ether waves received from the sun would change the quantity of ozone and thus its hothouse effect on the earth. It has, however, never been proved that this ozone exists, and it is extremely doubtful if it is the cause of any temperature changes.

In the *fifth* place many of our abnormalities in weather are said to have accidental causes. This in a sense is a misnomer as there are no accidents in nature. When the causes are many and minute, and when the relation between cause and effect is impossible to trace, we are prone to consider the causes as accidental. The story of how a Kansas grasshopper caused a drought in New England illustrates this in a fanciful way. This obscure cause, the Kansas grasshopper, had pulled down several heads of wheat in a Kansas wheat field. The farmer, viewing the field, noticed in particular this destruction and decided to plow the wheat under rather than to harvest it. This changed the amount of moisture evaporated from the soil to such an extent that the passing LOWS were deflected from their course and brought no rain to New England. But let us pass to a more sensible illustration. It is June. A heavy thundershower brings nearly 2 inches of rain to a certain station and 20 miles away, at another, there is no rain. At the end of the month the rainfall at one station is normal and at the other it is 2 inches above normal. We say this abnormality is accidental. Rather the causes that produced a thundershower at one station and not at another were many, small, and there is no possibility of tracing the connection. Let us take a third illustration. December, 1923, was abnormally warm. It is still fresh in our minds, and it is always better to discuss an abnormality while it is still well remembered. This abnormality was pronounced. The greatest departure was +12°. In Williamstown the departure from normal was 8.9°. This is next to the largest in 40 years. This abnormality was widespread. It covered nearly the whole of the United States. This abnormality was long continued. It existed during November and a part of January.[6]

Such an abnormality as that can hardly result from small, insignificant, *accidental* causes. This can always be claimed when an abnormality is pronounced, widespread, and long continued. If not due to accidental causes, then why was December, 1923, so abnormal in temperature? It was not due to volcanic eruptions, for there had been none, and in any case they cause a decrease, not an increase, in temperature. The sun's activity and condition as evidenced by the solar constant and sun spots should next be considered. Table 9 contains the values of the solar constant and the Wolfer sun-spot numbers month by month for the last four years. The solar constant had been but little below normal for July, August, September, October, and November, 1923. During the last half of 1922 and the first half of 1923 it had been markedly below normal. A low value of the solar constant should cause most of the United States to be too warm. The disconcerting thing is that the abnormality of temperature did not continue of the same nature and amount for a much longer period. The year 1923 was the time of the sun-spot minimum. The lowest value for any month was that of 0.5° for August. The year as a whole averaged 5.5°. During a sun-spot minimum the earth as a whole should be about 0.5° F. warmer than normal. The disconcerting thing here is that each month of 1923 did not show the same amount and kind of abnormality, for more than a year was spent in passing through a very flat minimum. According to Kullmer's work, at the time of sun-spot minimum storms should be more common in an irregular middle belt across the United States and less common in belts above it and below it. The disconcerting thing here is that the area of abnormally high temperature covers all of these belts. Possibly some change in ocean surface temperature over a large area caused this abnormality of temperature in December. A change south of the Aleutian Islands would be the most likely cause. Perhaps the small value of the solar constant a year before and continuing for a year or more weakened the Japan Current, so that the Aleutian Islands LOW and thus also the HIGH in northern Canada. were weaker than usual. This would cause fewer cold waves, and thus make the temperature unusually high, We are waiting here for the results of the investigations such as these by Sir Frederic Stupart along this line.

The problem of why December, 1923, was abnormally warm can also be approached from the other side. December was abnormally warm because the moving areas of high pressure entered the United States from the Pacific along the Oregon and California coasts rather than from Alberta. They often dropped far to the south, moved slowly, and were not accompanied by cold waves—. those vast outpourings of cold air which come down from Canada and sweep over a large portion of the United States at times. But why did these highs have such unusual characteristics? Probably because the semipermanent HIGH which in winter covers the north-central portion of Canada was weak. And why was it abnormally weak? Here we lose the scent and have penetrated as far as we can at present from this side of the question. But in general terms it amounts to this. Our weather is absolutely controlled by the passing areas of low and high pressure. If a month is abnormal, it is because the direction and velocity of motion and the characteristics of the LOWS and HIGHS were different. Why are they different? Because the meteorological

[6] For details, the temperature charts in the MONTHLY WEATHER REVIEW for November and December, 1923, and January, 1924, should be consulted.

condition of the country is different or there is a difference in the semipermanent HIGHS and LOWS called the centers of action. The last are probably the most important. The outstanding question is why these semipermanent HIGHS and LOWS are different in different years.

These five causes of abnormalities which have been treated are the only ones which are known to have been investigated up to the present time.

In order to facilitate the intensive study of this very important problem of the cause of abnormalities, it is suggested that certain data might be published regularly each month in the MONTHLY WEATHER REVIEW, namely, the values of the solar constant; the values of the Wolfer sun-spot numbers; any definite information about volcanic eruptions, unusual oceanic surface temperatures, changes in the carbon dioxide or ozone content of the atmosphere; a more detailed description of the intensity and position of the semipermanent HIGHS and LOWS.

There is a crying need for a weather map of the whole Northern Hemisphere, if not for the world. Any change in the semipermanent HIGHS and LOWS would then become apparent at once. It is probably impossible at present to secure the observations in time and it is also too expensive. Perhaps the data could be obtained in in time to publish these daily maps in the MONTHLY WEATHER REVIEW for the month in question. A world meteorological foundation has been proposed. It has been stated that to gain the participation of America, some problem having a bearing upon American meteorology should be undertaken. What better problem could be undertaken than to secure sufficient data to make an excellent and complete daily weather map for the whole world and to make possible its speedy publication.

In concluding it may be said that this paper is unsatisfactory because it does not solve the immense problem of the cause of each and every abnormality. That solution seems a little beyond our reach at present. But progress, and distinct progress, has been made. It has been rather the purpose of this paper to point out the importance of the problem and the progress that has been made. It is a pressing problem. There is great eagerness for its solution. It is to be hoped that many meteorologists will lend their best efforts to its solution.

TABLE 1.—*The average monthly and the average yearly temperatures (°F.) 1816 to 1838, in Williamstown, Mass.*[1]

	January	February	March	April	May	June	July	August	September	October	November	December	Year
1816	21.0	25.2	29.3	42.7	[2]52.8	[2]60.8	[1]64.6	64.9	55.0	48.4	39.7	27.7	44.3
1817	20.8	15.1	28.6	43.8	54.3	[1]59.6	67.4	66.5	58.7	45.1	38.8	27.0	43.8
1818	20.3	[2]14.9	31.2	[2]39.1	53.6	68.5	71.3	65.9	55.6	48.1	39.8	22.0	44.2
1819	28.1	27.7	[1]25.9	42.2	55.3	67.2	70.3	69.0	[3]64.0	46.3	38.2	25.1	46.6
1820	19.8	29.4	30.7	45.6	54.7	67.4	[3]75.1	67.6	61.4	45.8	33.0	20.8	45.9
1821	17.5	29.6	30.0	41.2	55.9	68.0	67.8	68.3	61.2	46.1	35.9	24.2	45.5
1822	17.2	23.3	34.4	44.8	59.5	66.3	71.3	67.7	63.1	48.1	39.7	25.5	46.7
1823	22.9	16.9	30.6	47.1	54.9	65.4	71.2	67.7	56.1	44.3	[2]31.3	28.5	44.7
1824	26.1	24.4	31.4	45.7	55.1	67.5	67.7	[2]64.3	59.1	44.6	34.5	30.1	45.9
1825	23.1	26.9	36.4	46.1	57.3	70.0	74.9	68.8	58.4	50.8	35.0	28.8	48.0
1826	25.3	26.1	33.2	40.7	[3]64.9	68.9	71.0	69.6	62.8	50.1	36.9	26.5	48.0
1827	[2]16.4	25.6	33.2	48.1	57.3	65.4	69.5	66.6	59.9	49.2	[1]30.4	29.2	45.9
1828	28.2	[3]33.0	35.2	40.9	58.3	[3]71.7	69.2	[3]71.0	60.6	46.1	38.4	32.6	[3]48.8
1829	20.7	17.0	28.4	43.4	60.1	66.7	68.7	67.3	[1]53.7	47.9	35.9	[3]34.5	45.4
1830	20.6	21.0	34.0	[3]49.4	55.5	64.1	72.4	67.8	57.9	48.9	[3]43.1	30.7	47.1
1831	17.5	18.7	[3]37.9	46.8	60.8	71.1	71.4	69.0	59.2	49.9	30.1	[1]14.0	46.0
1832	23.4	23.8	33.7	41.3	54.2	66.2	68.5	67.9	58.5	48.0	38.0	27.6	45.9
1833	28.3	19.6	30.0	48.5	62.2	61.7	68.2	64.5	59.1	46.7	34.0	26.5	45.8
1824	19.9	32.5	34.6	47.3	57.7	63.2	73.3	67.5	60.2	44.0	33.7	23.0	46.4
1835	20.2	19.9	29.9	42.3	54.8	64.7	68.6	66.1	[2]54.9	[3]51.5	36.5	20.2	44.1
1836	22.8	15.7	[2]26.1	40.4	55.9	62.4	69.8	[1]61.7	59.0	[1]40.5	32.8	23.6	[1]42.6
1837	[1]13.3	21.6	28.3	40.4	[1]51.9	63.4	[2]66.5	64.9	56.5	44.5	35.8	24.6	[2]42.6
1838	[3]29.2	[1]13.1	33.0	[1]37.9	54.0	68.5	72.2	66.4	59.1	[2]43.9	31.5	[2]18.7	43.9
Normal	21.8	22.7	31.6	43.7	56.6	66.0	70.0	67.0	58.9	46.9	36.1	25.7	45.6

[1] Lowest average. [2] Next lowest average. [3] Highest average.

TABLE 2.—*Lowest observed temperatures (°F.) 1816 to 1838, in Williamstown, Mass.*

	June	July	August
1816	[1]35.0	[1]43.0	[1]37.5
1817	[2]36.0	50.0	44.0
1818	49.6	53.5	45.0
1819	51.0	48.5	43.7
1820	43.3	[3]57.0	48.0
1821	43.0	48.7	47.0
1822	46.6	50.0	41.0
1823	46.0	52.4	48.0
1824	48.2	52.0	45.0
1825	55.0	56.0	53.3
1826	52.0	56.0	53.0
1827	44.8	52.0	43.0
1828	54.0	57.0	50.5
1829	48.5	51.8	[3]43.4
1830	49.8	54.5	[4]49.0
1831	46.0	50.8	40.5
1832	43.5	52.0	42.0
1833	[5]43.0	51.0	44.0
1834	42.0	[6]52.0	48.2
1835	49.3	54.0	48.0
1836	47.0	52.0	[2,7]39.5
1837	46.0	[8]54.0	[5]43.0
1838	50.0	52.5	[5]42.0
Average	46.5	53.2	45.1

[1] Lowest average. [2] Next lowest average. [3] 41 at SR. [4] 46½ at SR. [5] 39 at SR. [6] 46 at SR. [7] 38.5 at SR. [8] 48 at SR.

TABLE 3.—*The average difference between the minimum and the 7 a. m. temperature at Albany, N. Y.*

	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	Normal
June	2.8	4.2	3.8	4.1	3.4	4.8	5.7	4.6	4.9	5.0	1.3
July	2.8	2.7	3.9	3.4	3.7	4.0	3.9	4.1	4.6	5.0	3.4
August	3.5	3.4	3.7	3.6	3.1	2.8	4.1	2.7	3.9	3.6	3.4

TABLE 4.—*The average monthly temperatures (°F.) for 1816, at Williamstown, Mass.*

	January	February	March	April	May	June	July	August	September	October	November	December
1/3 (7 a. m.+2 p. m.+9 p. m)	21.0	25.2	29.3	42.7	52.8	60.8	64.6	64.9	55.0	48.4	39.7	27.7
1/4 (7 a.m.+2p.m.+9 p.m.+9p.m.)	20.9	24.7	28.7	41.8	51.8	60.2	63.6	64.1	54.0	47.6	39.5	27.4
Difference	0.1	0.5	0.6	0.9	1.0	0.6	1.0	0.8	1.0	0.8	0.2	0.3

TABLE 5.—*The average monthly and the average yearly temperatures (°F.) 1901 to 1923, in Williamstown, Mass.*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
1901	22.0	16.2	30.6	45.8	55.6	66.0	70.2	69.0	60.0	48.8	[1]31.4	25.2	45.1
1902	21.2	21.6	38.2	46.0	54.7	61.6	66.6	63.8	59.4	49.0	[3]42.2	22.5	45.6
1903	24.2	27.0	41.6	45.2	58.4	[1]59.6	67.2	[1]60.4	59.2	49.7	33.4	21.7	45.6
1904	14.7	16.0	30.0	40.7	59.6	64.8	66.8	62.2	57.3	46.2	32.0	19.2	[1]42.5
1905	18.0	15.5	30.8	44.4	56.1	62.9	69.6	63.9	58.2	49.0	35.2	29.6	44.4
1906	29.6	22.2	26.3	43.6	55.4	65.0	68.6	68.5	61.2	49.9	36.0	23.8	45.8
1907	22.5	15.2	34.2	[1]40.1	50.8	62.1	68.7	64.0	60.2	[1]44.2	37.1	30.8	44.2
1908	24.8	19.1	33.4	43.7	58.2	64.7	70.5	65.1	61.8	50.8	38.5	26.9	46.5
1909	25.1	27.7	30.3	43.8	54.9	64.7	66.8	64.7	58.9	46.5	41.0	23.3	45.6
1910	24.7	21.0	39.0	49.2	55.0	62.2	70.2	65.4	59.6	51.0	34.6	19.9	46.0
1911	26.6	24.1	29.7	42.2	[3]62.8	62.8	71.9	67.4	58.5	47.7	35.3	32.8	46.8
1912	14.8	18.5	28.2	44.6	57.5	62.2	69.5	64.2	59.4	50.3	39.1	32.5	45.1
1913	[3]33.8	21.3	37.8	46.9	54.5	64.8	69.0	66.9	57.7	53.4	41.7	29.8	[3]48.1
1914	21.9	[1]14.9	31.0	41.5	57.7	63.6	67.5	67.1	57.8	52.7	35.4	24.7	44.7
1915	26.1	[3]27.8	28.9	49.5	52.2	63.7	68.3	64.8	[3]63.2	50.3	38.7	26.2	46.6
1916	25.8	19.3	[1]22.3	43.7	56.0	61.0	71.3	68.9	59.4	49.5	36.8	25.8	45.0
1917	23.2	18.8	31.6	42.7	[1]47.7	64.3	70.0	[3]70.1	[1]55.8	45.8	32.6	[1]16.5	43.3
1918	[1]11.5	20.1	32.7	44.1	61.8	61.2	68.7	68.6	56.5	51.4	39.8	30.5	45.6
1919	27.1	26.4	36.2	43.0	56.2	[3]68.1	68.2	64.8	60.3	50.9	37.2	20.4	46.6
1920	13.4	20.2	32.3	41.1	53.0	62.8	66.8	62.3	61.0	[3]54.4	35.8	29.2	44.9
1921	25.6	26.4	[3]42.0	[3]50.7	57.6	64.4	[3]72.5	66.4	62.1	49.6	37.5	23.5	47.8
1922	18.6	25.6	33.8	43.6	58.2	67.0	69.2	65.3	60.9	48.4	37.8	26.2	46.3
1923	19.2	16.4	27.3	44.1	53.4	66.0	[1]66.1	66.5	61.0	48.2	37.9	[3]34.7	44.9
Normal	22.4	20.9	32.5	44.4	56.0	63.8	68.9	65.8	59.5	49.5	36.8	25.9	45.5

[1] Lowest average. [3] Highest average.

TABLE 6.—*Lowest minimum temperatures (°F.) 1901 to 1923, at Williamstown, Mass.*

	June	July	Aug.
1901	44	48	[3] 56
1902	41	47	44
1903	38	43	42
1904	41	44	[1] 35
1905	38	47	42
1906	38	48	46
1907	38	45	43
1908	37	48	40
1909	43	43	42
1910	37	49	43
1911	45	49	44
1912	[1] 35	[1] 41	[2] 38
1913	[2] 35	44	41
1914	42	47	45
1915	38	48	40
1916	40	47	46
1917	[3] 48	[3] 50	46
1918	37	[2] 42	42
1919	42	48	45
1920	38	44	44
1921	38	[3] 50	44
1922	43	47	45
1923	42	46	[2] 38
Average	39.9	46.3	43.1

[1] Lowest average. [2] Next lowest average. [3] Highest average.

TABLE 7.—*The departure from normal of the various months of 1816 (°F.)*

	January	February	March	April	May	June	July
Cambridge	+5.0	−0.6	−4.1	−2.5	−4.5	−6.0	−6.5
New Bedford	−2.2	+1.6	−1.9	−1.4	−2.5	−5.0	−5.8
New Haven	−4.0	0.0	−4.0	−5.0	−5.0	−7.0	−7.0
Salem	−0.4	+0.3	−4.7	−0.7	−3.0	−5.4	−5.7
Williamstown	−1.5	+4.0	+0.6	+0.7	−1.4	−3.2	−3.8
Do	−0.8	+2.5	−2.3	−1.0	−3.8	−5.2	−5.4

	August	September	October	November	December	Year	Normal based on—
Cambridge	−3.2	−4.8	−0.1	+3.5	−2.3	−2.2	
New Bedford	−2.2	−3.3	+0.8	+2.6	+2.0	−1.4	1813–1856
New Haven	−2.0	−5.0	−1.0	+2.0	0.0	−3.0	1778–1920
Salem	−1.6	+0.5	−1.6	+1.7	+1.8	−1.5	1786–1828
Williamstown	−2.0	−3.4	+1.4	+0.6	+2.3	−0.5	1816–1819
Do	−2.1	−3.9	+1.5	+3.6	+2.0	−1.3	1816–1838

TABLE 8.—*The departure from normal of the months of various years at Williamstown, Mass., °F.*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
1816	−0.8	+2.5	−2.3	−1.0	−3.8	−5.2	−5.4	−2.1	−3.9	+1.5	+3.6	+2.0	−1.3
1817	−1.0	−7.6	−3.0	+0.1	−2.3	−6.4	−2.6	−0.5	−0.2	−1.8	+2.7	+1.3	−1.8
1835	−1.6	−2.8	−1.7	−1.4	−1.8	−1.3	−1.4	−0.9	−4.0	+4.6	+0.4	−5.5	−1.5
1836	+1.0	−7.0	−5.5	−3.3	−0.7	−3.6	−0.2	−5.3	+0.1	−6.4	−3.3	−2.1	−3.0
1837	−8.5	−1.1	−3.3	−3.3	−4.7	−2.6	−3.5	−2.1	−2.4	−2.4	−0.3	−1.1	−3.9
1838	+7.4	−9.6	+1.4	−5.8	−2.6	+2.5	+2.2	−0.6	+0.2	−3.0	−4.6	−7.0	−1.6
1912	−7.6	−2.4	−4.3	+0.2	+1.5	−1.6	+0.6	−1.6	−0.1	+0.8	+2.3	+6.6	−0.4
1913	+11.4	+0.4	+5.3	+2.5	−1.5	+1.0	+0.1	+1.1	−1.8	+3.9	+4.9	+3.9	+2.6

TABLE 9.—*Solar constant values and Wolfer, 1920–1924*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
1920	1,964	1.956	1.946	1.952	1.953	1.939	1.945	1.930	1.942	1.943	1.949	1.955	1.948
1921	1.958	1.951	1.946	1.947	1.949	1.934	1.945	1.936	1.944	1.947	1.954	1.951	1.947
1922	1.945	1.946	1.934	1.927	1.927	1.917	1.911	1.917	1.903	1.918	1.919	1.927	1.924
1923	1.926	1.915	1.913	1.913	1.915	1.916	1.926	1.931	1.933	1.930	1.931	1.923	1.923
1924	1.930	1.919	1.916	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

WOLFER SUN-SPOT NUMBERS, 1920–1924

1920	57.3	50.9	71.9	14.3	33.7	38.8	26.5	18.6	38.7	48.8	24.6	39.9	38.7
1921	28.8	27.6	27.5	30.5	22.3	34.5	42.4	20.8	16.7	16.1	13.4	15.7	24.7
1922	10.2	27.9	60.0	11.4	7.7	5.8	9.7	5.3	5.2	8.1	6.7	18.7	14.7
1923	5.3	1.6	4.0	5.4	3.2	9.0	3.7	0.5	13.7	11.5	7.3	1.1	5.5
1924	0.7	5.7	2.2	11.5	20.7	24.8	-----	-----	-----	-----	-----	-----	-----

A NEW CLASSIFICATION OF TYPHOONS OF THE FAR EAST [1]

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INTRODUCTION

Cyclonic storms have often played a part in the history of nations. The wreck of the Spanish Armada in 1588 is probably the best-known illustration. In the east, there is a singular parallel in the complete demolition of the Mongolian fleet by a typhoon in the early summer of 1281, during Kublai Khan's invasion of Japan. The immediate cause of this expedition was the execution of Kublai's ambassador by the Japanese emperor in the spring of 1280. The next year, Kublai sent an army of 100,000 men, who embarked in 3,500 ships, to undertake the subjugation of Japan. On July 17, 1281,[2] just at the beginning of the typhoon season, a violent tropical storm came up which sank most of the ships of the grand fleet, then anchored off the coast of Kiushiu Island. Of the 100,000 men on board the ships, only 3 returned to China alive.

In most recent times, all the far Eastern countries have paid heavy tolls to these terrible scourges. During the Cantabria cyclone of September, 1905, hundreds of thousands of dollars' worth of property was destroyed in southern Luzon and in the Visayas, and more than 140 people were killed. In the typhoon of September 7–12, 1904, 4,000 persons were killed in Hué, the capital of Annam. A storm wave caused by the Shanghai cyclone of 1905 overwhelmed the island of Tsun-Ming off the coast of Shanghai, and several thousand persons were drowned. A great flood accompanying the typhoon of August 7–11, 1910, killed more than 1,200 people in Japan. More recently, the Swatow typhoon of August 2, 1922, brought calamities to the region around Swatow; more than 5,000 people were killed or drowned in Swatow alone.

Before considering the characteristics and habits of typhoons, it is necessary to define what is meant by "typhoon." Algué has described a typhoon as a vast whirl of aerial currents which surround a central calm space of relatively small dimensions called the "vortex," or center of the storm. The central region of calm, relative or absolute, is, however, only found in the better-developed tropical cyclones. In the reports of the Zikawei Observatory, practically all the tropical storms are called typhoons. Because of the diversity in the use of the word, a clear distinction between a typhoon and a mere depression, based upon the intensity of the storm, has to be made.

The barometric readings do not indicate the intensity of a cylcone, for this intensity depends upon the rate of

[1] Acknowledgments.—With a few alterations this paper was written in 1918 to fulfill part of the requirement for the degree of Ph. D. in Harvard University, Cambridge, Mass. Since then, quite a few papers have been written on the subject of the typhoons of the Far East, the most notable being Father Louis Froc's Atlas of the Tracks of 620 Typhoons 1893–1918, published by Zikawei observatory, Shanghai. In view of the new light thrown upon the subject by the recent papers, additional footnotes have been inserted wherever occasion demands. The subject of this thesis was chosen mainly because of the economic importance of typhoons in the Far East. The writer has also an added interest because of the fact that he is a native of a region on the coast of China which is visited by those storms. The material used in this report has largely been obtained from the annual and monthly meteorological reports of the Zikawei Observatory (Bulletin des Observations), the Journal of the Meteorological Society of Japan, the annual reports of the Central Meteorological Observatory of Japan, and especially from the monthly bulletin of the Philippines Weather Bureau; without these publications this investigation would not have been possible. It has been the privilege of the writer to carry out his work under the supervision of Prof. Robert DeCourcy Ward, to whose advice, encouragement, and helpful suggestions the writer takes this opportunity to express his sincere thanks.

[2] The Chinese date for this memorable event is the first day of the seventh month in the eighteenth year of Chi-Yuen, Juen dynasty. In western chronology, this is July 17, 1281 (according to Rev. P. Hoang's Concordance des Chronologies neomeniques, Chinoise et Européenne, Shanghai, 1910, p. 269.) In this connection, attention may be called to an interesting book written by a Japanese author, N. Yamada, The Mongol Invasion of Japan, published in London in 1916.